B19485P

DERMATOLOGICAL CUTTING AND ABLATING DEVICE

PRIORITY INFORMATION

This application is a continuation-in-part of co-pending U.S. Application Number 09/298,112 filed on April 23, 1999 and entitled ELECTROMAGNETICALLY INDUCED CUTTING WITH ATOMIZED FLUID PARTICLES FOR DERMATOLOGICAL APPLICATIONS, which claims the benefit of U.S. Provisional Application No. 60/083,003 filed on April 24, 1998 and entitled ELECTROMAGNETICALLY INDUCED CUTTING WITH ATOMIZED FLUID PARTICLES FOR DERMATOLOGICAL APPLICATIONS, the contents of both which are expressly incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to medical apparatus and, more particularly, to methods and apparatus for cutting and removing tissue and other materials.

2. Description of Related Art

Turning to Figure 1, a prior art optical cutter includes a fiber guide tube 5, a water line 7, an air line 9, and an air knife line 11 for supplying pressurized air. A cap 15 fits onto the hand-held apparatus 13 and is secured via threads 17. The fiber guide tube 5 abuts within a cylindrical metal piece 19. Another cylindrical metal piece 21 is a part of the cap 15. The pressurized air from the air knife line 11 surrounds and cools the laser as the laser bridges the gap between the two metal cylindrical objects 19 and 21. Air from the air knife line 11 flows out of the two exhausts 25 and 27 after cooling the interface between elements 19 and 21.

The Nd:YAG laser energy exits from the fiber guide tube 23 and is applied to a target surface of the patient. Water from the water line 7 and pressurized air

from the air line 9 are forced into the mixing chamber 29. The air and water mixture is very turbulent in the mixing chamber 29, and exits this chamber through a mesh screen with small holes 31. The air and water mixture travels along the outside of the fiber guide tube 23, and then leaves the tube and contacts the area of surgery.

Other prior art devices include optical cutting systems utilizing the expansion of water to destroy and remove tooth material, such as disclosed in U.S. Patent No. 5,199,870 to Steiner et al. This prior art approach requires a film of liquid having a thickness of between 10 and 200 μm. U.S. Patent No. 5,267,856 to Wolbarsht et al. discloses a cutting apparatus that requires water to be inserted into pores of a material and then irradiated with laser energy. In both patents the precision and accuracy of the cut is highly dependent upon the precision and accuracy of the water film on the material or the water within the pores.

Summary of the Invention

The present invention discloses an electromagnetically induced cutting mechanism, which can provide accurate cutting operations on hard and soft tissues, and other materials as well. Soft tissues may include fat, skin, mucosa, gingiva, muscle, heart, liver, kidney, brain, eye, and vessels, and hard tissue may include tooth enamel, tooth dentin, tooth cementum, tooth decay, amalgam, composites materials, tarter and calculus, bone and cartilage.

The electromagnetically induced cutter is capable of providing extremely fine and smooth incisions, irrespective of the cutting surface. Additionally, a user programmable combination of atomized fluid particles or of a composition of moist air allows for user control of various cutting parameters. The various cutting parameters may also be controlled by changing spray nozzles and electromagnetic energy source parameters. The present invention further does not require any films of water or any particularly porous surfaces to obtain very accurate and controlled cutting. Since substantial thermal heating is reduced or substantially eliminated by

the cutting mechanism in one embodiment, thermal damage can be attenuated or eliminated. Adjacent tissue can be spared from substantial thermal damage.

The electromagnetically induced cutter of the present invention includes an electromagnetic energy source, which focuses electromagnetic energy into a volume of air adjacent to a target surface. The target surface may comprise skin, for example. A user input device can specify a type of cut to be performed, and an atomizer (or moist air generating device) responsive to the user input device places moist air and/or a combination of atomized fluid particles into the volume of air. The electromagnetic energy is focused into the volume of air, and the wavelength of the electromagnetic energy is selected to be substantially absorbed by moisture in the air and/or the atomized fluid particles in the volume of air. Upon absorption of the electromagnetic energy the moisture and/or atomized fluid particles impart cutting forces onto the target surface.

The invention, together with additional features and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying illustrative drawings.

Brief Description of the Drawings

Figure 1 is a conventional optical cutter apparatus;

Figure 2 is a schematic block diagram illustrating the electromagnetically induced cutter of the present invention;

Figure 3 illustrates one embodiment of the electromagnetically induced cutter of the present invention;

Figures 4a and 4b illustrate a preferred embodiment of the electromagnetically induced cutter;

Figure 5 illustrates a control panel for programming the combination of atomized fluid particles according to the present invention;

Figure 6 is a plot of particle size versus fluid pressure;

Figure 7 is a plot of particle velocity versus fluid pressure;

Figure 8 is a schematic diagram illustrating a fluid particle, a source of electromagnetic energy, and a target surface according to the present invention; and

Figures 9-19 illustrate various configurations of the present invention for imparting electromagnetically-induced disruptive forces onto a target surface;

Figure 20 illustrates a hand-held piece having a parabolic mirror or prism, a moisture source, and a suction source;

Figure 21 illustrates a hand-held piece having a fiber optic, a moisture source, and a suction source;

Figure 22 illustrates a hand-held piece having a parabolic mirror or prism, at least two moisture sources, and a suction source;

Figure 23 illustrates a hand-held piece having a fiber optic, at least two moisture sources, and a suction source;

Figure 24 illustrates a hand-held piece having a fiber optic, a mixing chamber, and a suction source;

Figure 25 illustrates a hand-held piece having a parabolic mirror or prism, at least one moisture source, and a suction source; and

Figure 26 illustrates a hand-held piece having a removable spacer and moisture source.

Description of the Presently Preferred Embodiments

Figure 2 is a block diagram illustrating an electromagnetically induced cutter in accordance with the present invention. An electromagnetic energy source 51 is coupled to both a controller 53 and a delivery system 55. The delivery system 55 imparts forces onto the target surface 57. As presently embodied, the delivery system 55 comprises a fiber optic guide for routing the laser 51 into an interaction zone 59, located above the target surface 57. The delivery system 55 further comprises an atomizer for delivering user-specified combinations of atomized fluid particles into the interaction zone 59. The controller 53 controls various operating parameters of the laser 51, and further controls specific characteristics of the user-

specified combination of atomized fluid particles output from the delivery system 55.

Figure 3 shows a simple embodiment of the electromagnetically induced cutter of the present invention, in which a fiber optic guide 61, an air tube 63, and a water tube 65 are placed within a hand-held housing 67. The water tube 65 is operated under a relatively low pressure, and the air tube 63 is operated under a relatively high pressure. The laser energy from the fiber optic guide 61 focuses onto a combination of air and water, from the air tube 63 and the water tube 65, at the interaction zone 59. Atomized fluid particles in the air and water mixture absorb energy from the laser energy of the fiber optic tube 61, and explode. The explosive forces from these atomized fluid particles impart cutting forces onto the target surface 57.

Turning back to Figure 1, the prior art optical cutter focuses laser energy onto a target surface at an area A, for example, and the electromagnetically induced cutter of the present invention focuses laser energy into an interaction zone B, for example. The prior art optical cutter uses the laser energy directly to cut tissue, and the electromagnetically induced cutter of the present invention uses at least part of the laser energy to expand atomized fluid particles to thus impart cutting forces onto the target surface. The prior art optical cutter must use a large amount of laser energy to cut the area of interest, and also must use a large amount of water to both cool this area of interest and remove cut tissue.

In contrast, the electromagnetically induced cutter of the present invention in one implementation uses a relatively small amount of water and, further, uses only a small amount of laser energy to expand atomized fluid particles generated from the water. According to the electromagnetically induced cutter of the present invention, water is not needed to cool the area of surgery, since the exploded atomized fluid particles are cooled by exothermic reactions before they contact the target surface. Thus, atomized fluid particles of the present invention are heated, expanded, and cooled before contacting the target surface. The electromagnetically

induced cutter of the present invention is thus capable of cutting without charring or discoloration.

Figure 4a illustrates a presently preferred embodiment of the electromagnetically induced cutter. The atomizer for generating atomized fluid particles comprises a nozzle 71, which may be interchanged with other nozzles (not shown) for obtaining various spatial distributions of the atomized fluid particles, according to the type of cut desired. One or more additional nozzles 72, shown in phantom lines, may also be used. The cutting power of the electromagnetically induced cutter may further be controlled by a user control 75 (Figure 4b). In a simple embodiment, the user control 75 controls the air and water pressure entering into the nozzle 71. The nozzle 71 is thus capable of generating many different user-specified combinations of atomized fluid particles and aerosolized sprays.

Intense energy is emitted from the fiber optic guide 23. This intense energy is preferably generated from a coherent source, such as a laser. In the presently preferred embodiment, the laser comprises either an erbium, chromium, yttrium, scandium, gallium garnet (Er, Cr:YSGG) solid state laser, which generates electromagnetic energy having a wavelength in a range of 2.70 to 2.80 microns, or an erbium, yttrium, aluminum garnet (Er:YAG) solid state laser, which generates electromagnetic energy having a wavelength of 2.94 microns. As presently preferred, the Er, Cr:YSGG solid state laser has a wavelength of approximately 2.78 microns and the Er:YAG solid state laser has a wavelength of approximately 2.94 microns.

Although the fluid emitted from the nozzle 71 preferably comprises water, other fluids may be used and appropriate wavelengths of the electromagnetic energy source may be selected to allow for high absorption by the fluid. Other possible laser systems include an erbium, yttrium, scandium, gallium garnet (Er:YSGG) solid state laser, which generates electromagnetic energy having a wavelength in a range of 2.70 to 2.80 microns; an erbium, yttrium, aluminum garnet (Er:YAG) solid state laser, which generates electromagnetic energy having a wavelength of 2.94 microns; chromium, thulium, erbium, yttrium, aluminum garnet

(CTE:YAG) solid state laser, which generates electromagnetic energy having a wavelength of 2.69 microns; erbium, yttrium orthoaluminate (Er:YALO3) solid state laser, which generates electromagnetic energy having a wavelength in a range of 2.71 to 2.86 microns; holmium, yttrium, aluminum garnet (Ho:YAG) solid state laser, which generates electromagnetic energy having a wavelength of 2.10 microns; quadrupled neodymium, yttrium, aluminum garnet (quadrupled Nd:YAG) solid state laser, which generates electromagnetic energy having a wavelength of 266 nanometers; argon fluoride (ArF) excimer laser, which generates electromagnetic energy having a wavelength of 193 nanometers; xenon chloride (XeCl) excimer laser, which generates electromagnetic energy having a wavelength of 308 nanometers; krypton fluoride (KrF) excimer laser, which generates electromagnetic energy having a wavelength of 248 nanometers; and carbon dioxide (CO2), which generates electromagnetic energy having a wavelength in a range of 9.0 to 10.6 microns. Water is chosen as the preferred fluid because of its biocompatibility, abundance, and low cost. The actual fluid used may vary as long as it is properly matched (meaning it is highly absorbed) to the selected electromagnetic energy source (i.e. laser) wavelength.

The electromagnetic energy source can be configured with the repetition rate greater than 1 Hz, the pulse duration range between 1 picosecond and 1000 microseconds, and the energy greater than 1 milliJoule per pulse. According to one operating mode of the present invention, the electromagnetic energy source has a wavelength of approximately 2.78 microns, a repetition rate of 20 Hz, a pulse duration of 140 microseconds, and an energy between 1 and 300 milliJoules per pulse.

In one preferred embodiment the electromagnetic energy source has a pulse duration on the order of nanoseconds, which is obtained by Q-switching the electromagnetic energy source, and in another preferred embodiment the electromagnetic energy source has a pulse duration on the order of picoseconds, which is obtained by mode locking the electromagnetic energy source. Q-switching is a conventional mode of laser operation which is extensively employed

for the generation of high pulse power. The textbook, Solid-State Laser Engineering, Fourth Extensively Revised and Updated Edition, by Walter Koechner and published in 1996, the entire contents of which are expressly incorporated herein by reference, discloses Q-switching laser theory and various Q-switching devices. Q-switching devices generally inhibit laser action during the pump cycle by either blocking the light path, causing a mirror misalignment, or reducing the reflectivity of one of the resonator mirrors. Near the end of the flashlamp pulse, when maximum energy has been stored in the laser rod, a high Q-condition is established and a giant pulse is emitted from the laser. Very fast electronically controlled optical shutters can be made by using the electro-optic effect in crystals or liquids. An acousto-optic Q-switch launches an ultrasonic wave into a block of transparent optical material, usually fused silica. Chapter eight of the textbook, Solid-State Laser Engineering, Fourth Extensively Revised and Updated Edition, discloses the above-mentioned and other various Q-switching devices. Mode locking is a conventional procedure which phase-locks the longitudinal modes of the laser and which uses a pulse width that is inversely related to the bandwidth of the laser emission. Mode locking is discussed on pages 500-561 of the above-mentioned textbook entitled, Solid-State Laser Engineering, Fourth Extensively Revised and Updated Edition.

The atomized fluid particles provide cutting forces when they absorb the electromagnetic energy within the interaction zone. These atomized fluid particles, however, can provide a second function of cleaning and cooling the fiber optic guide from which the electromagnetic energy is output. The delivery system 55 (Figure 2) for delivering the electromagnetic energy can include a fiber optic energy guide or equivalent which attaches to the laser system and travels to the desired work site. Fiber optics or waveguides are typically long, thin and lightweight, and are easily manipulated. Fiber optics can be made of calcium fluoride (CaF), calcium oxide (CaO_2), zirconium oxide (ZrO_2), zirconium fluoride (ZrF), sapphire, hollow waveguide, liquid core, TeX glass, quartz silica, germanium sulfide, arsenic sulfide, germanium oxide (GeO_2), and other materials.

Other delivery systems include devices comprising mirrors, lenses and other optical components where the energy travels through a cavity, is directed by various mirrors, and is focused onto the targeted cutting site with specific lenses. The preferred embodiment of light delivery for medical applications of the present invention is through a fiber optic conductor, because of its light weight, lower cost, and ability to be packaged inside of a handpiece of familiar size and weight to the surgeon, dentist, or clinician. In other applications, non-fiber optic systems may be used.

The nozzle 71 can be employed to create an engineered combination of small particles of the chosen fluid. The nozzle 71 may comprise several different designs including liquid only, air blast, air assist, swirl, solid cone, etc. When fluid exits the nozzle 71 at a given pressure and rate, it is transformed into particles of user-controllable sizes, velocities, and spatial distributions. The nozzle may have spherical, oval, or other shaped openings of any of a variety of different sizes, according to design parameters.

Figure 5 illustrates a control panel 77 for allowing user-programmability of the atomized fluid particles. By changing the pressure and flow rates of the fluid, for example, the user can control the atomized fluid particle characteristics. These characteristics determine absorption efficiency of the laser energy, and the subsequent cutting effectiveness of the electromagnetically induced cutter. This control panel may comprise, for example, a fluid particle size control 78, a fluid particle velocity control 79, a cone angle control 80, an average power control 81, a repetition rate 82 and a fiber selector 83.

The cone angle may be controlled, for example, by changing the physical structure of the nozzle 71. Various nozzles 71 may be interchangeably placed on the electromagnetically induced cutter. Alternatively, the physical structure of a single nozzle 71 may be changed.

Figure 6 illustrates a plot 85 of mean fluid particle size versus pressure. According to this figure, when the pressure through the nozzle 71 is increased, the mean fluid particle size of the atomized fluid particles decreases. The plot 87 of

Figure 7 shows that the mean fluid particle velocity of these atomized fluid particles can increase with increasing pressure.

The fiber optic guide 23 (Figure 4a) can be placed into close proximity of the target surface. This fiber optic guide 23, however, preferably does not actually contact the target surface. Since the atomized fluid particles from the nozzle 71 are placed into the interaction zone 59, the purpose of the fiber optic guide 23 can be for placing laser energy into this interaction zone, as well. One feature of the present invention is the formation of the fiber optic guide 23 of straight or bent sapphire. Regardless of the composition of the fiber optic guide 23, however, another feature of the present invention is the cleaning effect of the air and water, from the nozzle 71, on the fiber optic guide 23.

The present inventors have found that this cleaning effect is optimal when the nozzle 71 is pointed somewhat directly at the target surface. For example, debris from the cutting are removed by the spray from the nozzle 71.

Additionally, the present inventors have found that this orientation of the nozzle 71, pointed toward the target surface, enhances the cutting efficiency of the present invention. Each atomized fluid particle contains a small amount of initial kinetic energy in the direction of the target surface. When electromagnetic energy from the fiber optic guide 23 contacts an atomized fluid particle, the exterior surface of the fluid particle acts as a focusing lens to focus the energy into the water particle's interior. As shown in Figure 8, the water particle 101 has an illuminated side 103, a shaded side 105, and a particle velocity 107. The focused electromagnetic energy is absorbed by the water particle 101, causing the interior of the water particle to heat and explode rapidly. This exothermic explosion cools the remaining portions of the exploded water particle 101. The surrounding atomized fluid particles further enhance cooling of the portions of the exploded water particle 101. A pressure-wave is generated from this explosion. This pressure-wave, and the portions of the exploded water particle 101 of increased kinetic energy, are directed toward the target surface 107. The incident portions from the original exploded water particle 101, which are now traveling at high

velocities with high kinetic energies, and the pressure-wave, can impart strong, concentrated, at least partially mechanical forces onto the target surface 107.

These at least partially mechanical forces can cause the target surface 107 to break apart from the material surface through a "chipping away" action. The target surface 107 does not undergo vaporization, disintegration, or charring. The chipping away process can be repeated by the present invention until the desired amount of material has been removed from the target surface 107. Unlike prior art systems, the present invention does not require a thin layer of fluid. In fact, it is preferred that a thin layer of fluid does not cover the target surface, since this insulation layer would interfere with the above-described interaction process.

The nozzle 71 is preferably configured to produce atomized sprays with a range of fluid particle sizes narrowly distributed about a mean value. The user input device for controlling cutting efficiency may comprise a simple pressure and flow rate gauge 75 (Figure 4b) or may comprise a control panel as shown in Figure 5, for example. Upon a user input for a high resolution cut, relatively small fluid particles are generated by the nozzle 71. Relatively large fluid particles are generated for a user input specifying a low resolution cut. A user input specifying a deep penetration cut causes the nozzle 71 to generate a relatively low density distribution of fluid particles, and a user input specifying a shallow penetration cut causes the nozzle 71 to generate a relatively high density distribution of fluid particles. If the user input device comprises the simple pressure and flow rate gauge 75 of Figure 4b, then a relatively low density distribution of relatively small fluid particles can be generated in response to a user input specifying a high cutting efficiency. Similarly, a relatively high density distribution of relatively large fluid particles can be generated in response to a user input specifying a low cutting efficiency.

Soft tissues may include fat, skin, mucosa, gingiva, muscle, heart, liver, kidney, brain, eye, and vessels, and hard tissue may include tooth enamel, tooth dentin, tooth cementum, tooth decay, amalgam, composites materials, tarter and calculus, bone, and cartilage. The term "fat" refers to animal tissue consisting of

cells distended with greasy or oily matter. Other soft tissues such as breast tissue, lymphangiomas, and hemangiomas are also contemplated. The hard and soft tissues may comprise human tissue or other animal tissue. Other materials may include glass and semiconductor chip surfaces, for example. The electromagnetically induced cutting mechanism can be further be used to cut or ablate other biological materials, ceramics, cements, polymers, porcelain, and implantable materials and devices including metals, ceramics, and polymers. The electromagnetically induced cutting mechanism can also be used to cut or ablate surfaces of metals, plastics, polymers, rubber, glass and crystalline materials, concrete, wood, cloth, paper, leather, plants, and other man-made and naturally occurring materials. Biological materials can include plaque, tartar, a biological layer or film of organic consistency, a smear layer, a polysaccharide layer, and a plaque layer. A smear layer may comprise fragmented biological material, including proteins, and may include living or decayed items, or combinations thereof. A polysaccharide layer will often comprise a colloidal suspension of food residue and saliva. Plaque refers to a film including food and saliva, which often traps and harbors bacteria therein. These layers or films may be disposed on teeth, other biological surfaces, and nonbiological surfaces. Metals can include, for example, aluminum, copper, and iron.

These various parameters can be adjusted according to the type of cut and the type of target surface. Hard tissues include tooth enamel, tooth dentin, tooth cementum, bone, and cartilage. Soft tissues, which the electromagnetically induced cutter of the present invention is also adapted to cut, include skin, mucosa, gingiva, muscle, heart, liver, kidney, brain, eye, and vessels. Other materials may include glass or crystalline materials and semiconductor chip surfaces, for example. In the case of bone tissues, for example, a portion of cancer affected bone may be removed by the electromagnetically induced cutter of the present invention. The electromagnetically induced cutter of the present invention provides a clean, high-precision cut with minimized cross-contamination, and thus allows for a precise removal of the cancer affected bone. After the bone is cut, it tends to grow back

with an increased success rate and with a reduction in the likelihood of cross-contamination.

A user may adjust the combination of atomized fluid particles exiting the nozzle 71 to efficiently implement cooling and cleaning of the fiber optic guide 23 (Figure 4a), as well. According to the present invention, the combination of atomized fluid particles may comprise a distribution, velocity, and mean diameter to effectively cool the fiber optic guide 23, while simultaneously keeping the fiber optic guide 23 clean of particular debris which may be introduced thereon by the surgical site.

Looking again at Figure 8, electromagnetic energy contacts each atomized fluid particle 101 on its illuminated side 103 and penetrates the atomized fluid particle to a certain depth. The focused electromagnetic energy is absorbed by the fluid, inducing explosive vaporization of the atomized fluid particle 101.

The diameters of the atomized fluid particles can be less than, almost equal to, or greater than the wavelength of the incident electromagnetic energy. In each of these three cases, a different interaction occurs between the electromagnetic energy and the atomized fluid particle. When the atomized fluid particle diameter is less than the wavelength of the electromagnetic energy (d<□), the complete volume of fluid inside of the fluid particle 101 absorbs the laser energy, inducing explosive vaporization. The fluid particle 101 explodes, ejecting its contents radially. As a result of this interaction, radial pressure-waves from the explosion are created and projected in the direction of propagation. The resulting portions from the explosion of the water particle 101, and the pressure-wave, produce the "chipping away" effect of cutting and removing of materials from the target surface 107. When the fluid particle 101 has a diameter, which is approximately equal to the wavelength of the electromagnetic energy (d̃□), the laser energy travels through the fluid particle 101 before becoming absorbed by the fluid therein. Once absorbed, the distal side (laser energy exit side) of the fluid particle heats up, and explosive vaporization occurs. In this case, internal particle fluid is violently ejected through the fluid particle's distal side, and moves rapidly with the explosive

pressure-wave toward the target surface. The laser energy is able to penetrate the fluid particle 101 and to be absorbed within a depth close to the size of the particle's diameter. When the diameter of the fluid particle is larger than the wavelength of the electromagnetic energy ($d>\lambda$), the laser energy penetrates the fluid particle 101 only a small distance through the illuminated surface 103 and causes this illuminated surface 103 to vaporize. The vaporization of the illuminated surface 103 tends to propel the remaining portion of the fluid particle 101 toward the targeted material surface 107. Thus, a portion of the mass of the initial fluid particle 101 is converted into kinetic energy, to thereby propel the remaining portion of the fluid particle 101 toward the target surface with a high kinetic energy. This high kinetic energy is additive to the initial kinetic energy of the fluid particle 101. The effects can be visualized as a micro-hydro rocket with a jet tail, which helps propel the particle with high velocity toward the target surface 107. The electromagnetically induced cutter of the present invention can generate a high resolution cut. Unlike the cut of the prior art, the cut of the present invention is clean and precise. Among other advantages, this cut provides an ideal bonding surface, is accurate, and does not stress remaining materials surrounding the cut.

Figures 9-19 illustrate various configurations for imparting non-thermal or reduced-thermal electromagnetically-induced disruptive forces onto a target surface, such as skin. A primary purpose of the present invention is to place electromagnetic energy, from an Er, Cr:YSGG laser, for example, into an atomized distribution of fluid particles, above the target surface. The energy from the laser is absorbed by the atomized fluid particles, causing the atomized fluid particles to expand and impart disruptive forces onto the target surface. A key feature in accordance with one aspect of the present invention is the absorption of the electromagnetic radiation by the fluid particles in the interaction zone, and the subsequent cutting imparted to the target surface. The term "cutting" is intended to encompass ablating and other types of disruptive forces that can be imparted onto a target surface.

Applicants have found that the distribution of particles imparted onto or directly in front of a fiber optic tip can form an interaction zone in front of the tip. The fiber optic serves to transport the concentrated electromagnetic energy through extraneous or stray fluid particles and into what Applicants refer to as an interaction zone. where high absorption of the electromagnetic energy subsequently occurs near to the target. Applicants have observed that the presently embodied electromagnetic radiation, which is highly absorbed by the specified fluid, and the combining of this electromagnetic radiation with the fluid particles at the tip of a fiber optic. will limit the penetration of the electromagnetic radiation through the mist to a predetermined depth. After this depth any electromagnetic radiation continuing through the mist is reduced or negligible, relative to the particular application at hand. during this cutting mode. As the electromagnetic radiation passes further and further into the interaction zone, its energy is absorbed more and more by the fluid particles, until hardly any, and eventually none. of the electromagnetic radiation remains. There is a point, or zone, wherein the thermal cutting forces are reduced substantially or eliminated, and wherein the cutting forces from the absorption of the electromagnetic radiation by the fluid particles, is optimal.

The high absorption of the electromagnetic energy by the fluid particles. resulting in expansion of the fluid particles, is a key element of one aspect of the present invention. A target must be placed within or near this interaction zone in order for the disruptive forces. from the absorption of the electromagnetic radiation by the fluid particles. to be optimally imparted onto the target surface.

One feature of the present invention is to maintain a bounded layer of fluid particles. which is not too thick and which is not too thin. The bounded layer of fluid particles may be of a relatively high density in order to optimize the absorption of electromagnetic energy in the layer and to ensure that substantial thermal cutting forces from the electromagnetic energy are attenuated or preferably substantially eliminated, being transformed into the fluid particles instead, so that the expansion of the fluid particles performs the cutting of the target surface. A

relatively low-density distribution of fluid particles, spanning a relatively large distance, would absorb the incident electromagnetic radiation, resulting in fluid particles expanding well above the target surface. Any remaining radiation in the fluid particle distribution near the target surface would be too weak to induce the required high absorption and resulting cutting forces.

In addition to being bounded to enable the delivery of concentrated electromagnetic energy into the layer of fluid particles, the layer should be bounded to facilitate the very-close positioning of the target surface to the incident electromagnetic radiation. More particularly, the target surface should be placed at the boundary or within the interaction zone, so that the disruptive forces resulting from the expansion of the fluid particles occur near the target and do not need to travel far before being imparted onto the target. Thus, it can be seen that a fiber optic tip placed into a distribution of fluid particles and, additionally, placed in close proximity (2-3 mm, for example) of a target surface, creates a thin layer of fluid particles between the incident, concentrated electromagnetic energy and the target surface. Other distances are possible within the scope of the present invention, depending on, for example, the selected laser intensity and wavelength, the selected fluid, and the selected distribution of atomized fluid particles. The below embodiments disclose, for example, other means for creating a bounded layer of fluid particles between the incident, concentrated electromagnetic energy and the target surface.

Turning to Figure 9, an electromagnetically induced cutter 121 is illustrated comprising a laser 123, microprocessor 125 and user interface 127. The electromagnetically induced cutter 121 further comprises an air and/or water source 129 for supplying one or more atomization nozzles 131 with air and/or water. A scanning housing 133 is connected between the motor 135 and the air and/or water supply 129. The scanning housing 133 inputs optical energy from the laser 123, and further inputs air and/or water from the air and/or water supply 129. Both the motor135 and the laser 123 are preferably controlled by the microprocessor 125 in accordance with one or more user inputs from the user interface 127. The motor

135 is adapted to scan both the fiber optic 137 from the laser 123 and at least one atomization nozzle 131 connected to the air and/or water supply 129, to achieve predetermined scanning patterns on the surface of the target.

In the illustrated embodiment, the scanning housing 133 is placed directly onto or supported above the target, such as the patient's skin, and the motor 135 moves both the fiber optic 137 and the attached atomization nozzles 131, to achieve predetermined scanning patterns on the target. In the illustrated embodiment, the two atomization nozzles 131 are fixed to a fiber optic coupler 139 by arms, and the air and water lines 141 connected to the atomization nozzles 131 are flexible. Additionally, in one preferred embodiment, the fiber optic 137 from the laser within the scanning housing 133 is flexible to allow deflection by the motor 135. U.S. patent number 5,474,549 and U.S. Patent Number 5,336,217 disclose fibers that are deflected to achieve scanning patterns on a target surface. The entire contents of these two patents are incorporated herein by reference to illustrate structure which can be implemented by the present invention to achieve, for example, scanning.

A very broad aspect of the present invention comprises supplying an atomized distribution of fluid particles in the path of a beam to achieve electromagnetically induced cutting. The beam can be scanned, as shown in Figures 9 to 19, or a housing of the beam can be moved over the target surface to thereby scan or advance the beam, as shown in Figures 20-26. In the illustrated embodiment of Figure 9, the output tip of the fiber optic 137 is preferably maintained a few millimeters from the target. In the embodiment of Figure 9, the entire lower surface of the scanning housing 133 is open. Other embodiments may comprise smaller openings which are only large enough to allow energy from the scanned fiber optic 137 to exit the scanning housing. In modified embodiments, a transparent member may be provided over the lower surface of the scanning housing 133 or the smaller opening to protect the internal components of the scanning housing 133.

Figure 10 illustrates an embodiment wherein the scanning housing 133 comprises the motor 135. In the embodiment of Figure 10, a small opening exists, which as illustrated generally comprises a diameter equal to the distance between the two atomization nozzles 131. The size of this opening can be configured during design and manufacture thereof to accommodate the desired scanning patterns achievable by the motor and fiber optic combination. In Figure 10, a ring 143 is attached at the bottom of the scanning housing 133. In the absence of the ring 143, in an event in one embodiment where the scanning housing is placed on the target surface, such as skin, although such placement is not required, the fiber optic tip 145 is close to or touches the target surface. The ring 143 of Figure 10 can thus provide an exact spacing between the fiber optic tip 145 (for outputting radiation) and the target surface, by contacting the target or a perimeter surface of the target.

The ring can be configured to comprise a mist disk, as discussed in connection with Figures 11-16 below. In the embodiments of Figures 9 and 10, as well as the following embodiments discussed in connection with Figures 20-26, the microprocessor or other circuitry can be programmed or constructed to vary the velocities of the atomized fluid particles, the sizes of the atomized fluid particles, the distributions of the atomized fluid particles, as well as other parameters of the atomized fluid particles, in accordance with desired cuts to be achieved. Additionally, these parameters of the atomized fluid particles may be varied in accordance with the surface being disrupted (for example, particular type or condition of skin or other type of soft tissue) by the electromagnetically induced cutter. In the embodiments of Figures 9 and 10, as well as the additional embodiments illustrated in the following figures, a surface-profile imager/generator can be implemented to provide a computer generated model of a surface being scanned, as disclosed in U.S. Patent No. 5,588,428. A visible beam, for example, may be used to collect profile information of the skin target surface. The electromagnetic energy from the fiber optic tip can be scanned accordingly in the embodiments of Figures 9 and 10, and especially in the embodiments of Figures 11 to 13 where a collimated beam is not necessarily used. Additionally, the amount

and properties of the atomized fluid particles may be varied in accordance with different areas and/or disruptive forces desired to be imparted onto the modeled surface or different areas of the modeled surface.

In the embodiments of Figures 9 and 10, the actual optical fiber is scanned using a motor assembly. Although the optical fiber may be scanned using a motor assembly in Figures 11 and 12, one embodiment of these figures can comprise the scanning of non-collimated electromagnetic energy using reflectors and focusing lenses, as is known in the art. U.S. Patent Number 5,624,434, and patents and references cited therein, disclose apparatuses which scan a non-collimated beam using dynamically controlled deflectors, the contents of which are expressly incorporated herein by reference. In other embodiments, such as disclosed below in connection with Figures 20-26, similar technology may be incorporated in hand-held pieces, wherein a few or substantially all of the parts therein are fixed and do not move, and wherein the hand piece is moved instead. In Figure 11, a fiber optic feeds a scanning head with the laser energy from a laser 123, and subsequently, the laser energy exits the fiber optic and is deflected with motor-controlled mirrors or other means and is passed through focusing lenses at 146. The focused beam then passes through a mist disk 147 before impinging on the target surface. The mist disk 147 is preferably configured to generate a thin layer of atomized fluid particles just over the target. The mist disk 147 may be configured to have circular or other geometrical shapes. In the illustrated exemplary embodiment, the mist disk 147 generates a layer of atomized fluid particles that is approximately 2 to 3 millimeters thick. Thinner and thicker layers are possible in substantially modified embodiments.

The atomized fluid particles themselves are generally preferred to be on the order of microns in diameter. In a preferred embodiment, the atomized fluid particles have diameters within a range of about 40 to 60 microns. In other embodiments, the atomized fluid particles have diameters of approximately 200 microns. Other diameters are also possible in accordance with the present invention, so long as electromagnetically induced cutting is optimized for the

desired application or maximized and thermal effects, preferably, are attenuated or eliminated during implementation of substantially non-thermal cutting operations. Since the electromagnetic energy from the laser is preferably highly absorbed by the atomized fluid particles, for the reduced-thermal mode of cutting, the layer of atomized fluid particles just above the target should be relatively thin in the presently preferred embodiment. In alternative embodiments, the layer of atomized fluid particles may be greater than 2 to 3 millimeters, but the amount of laser energy and/or characteristics of the distribution of atomized fluid particles may need to be adjusted accordingly so that cutting is maximized and thermal effects are attenuated or eliminated during implementation of substantially non-thermal cutting operations. For example, for a substantially thicker layer of atomized fluid particles a substantially greater laser energy concentration may need to be introduced to penetrate the greater thickness of the layer of atomized fluid particles and to generate the preferred cutting effects on the surface. The dynamic deflecting and focusing system may comprise, for example, one or more motors controlling one or more deflecting lenses, and/or one or more focusing optics, for focusing the deflected electromagnetic energy above the target surface just above or within the mist disk. Each motor can comprise a galvanic motor or stepper motor, for example.

Figure 12 illustrates a schematic example where a motor 135 controls a reflector assembly 149, and a focusing assembly 151 is disposed between the reflector assembly 149 and the mist disk 147. A shutter 153 may be used, as shown in phantom in Figure 12, for blocking the electromagnetic energy during intermediate positions between deflections, as is known in the art. In accordance with the present invention, the mist disk 147 is placed between the target surface and the incident electromagnetic energy to provide the thin layer of atomized fluid particles. Figure 13 illustrates a very thin mist disk 147, for providing an even thinner distribution of atomized fluid particles between the incident electromagnetic energy and the target. In Figure 13, a motor135 is used to scan a fiber optic 137. A coupling 155 is illustrated in phantom to the right of the motor,

as an alternative to the coupling 157 illustrated below and to the right of the motor, for scanning the fiber optic 137. Positioning of the coupling connector further away from the output tip 145 of the fiber optic 137 results in small movements of the coupling connector for scanning the output tip 145 of the fiber optic 137. In the presently preferred embodiment, the fiber optic 137 is flexible in a region between where the fiber optic 137 enters the scanning housing and where the fiber optic is controlled by the motor 135. The fiber optic 137, however, is preferably rigid or stiff in a region between the coupling of the fiber optic by the motor 135 and the output tip 145 of the fiber optic 137.

Figures 14-16 illustrate exemplary embodiments of mist disks in accordance with the present invention. Figure 14a is a side-elevation view of a mist disk 160, and Figure 14b is a bottom planar view of a mist disk 160. Although mist disks are described and illustrated, any assembly for providing a thin layer of atomized fluid particles just above the target surface may be implemented, provided the laser energy can be concentrated into the layer of particles. For example, a single nozzle (without a mist disk) may be placed just adjacent to a fiber optic for providing an atomized distribution of fluid particles to the fiber optic or other means of introducing electromagnetic radiation, and the electromagnetic radiation may or may not be scanned. (See, for example, Figures 20-26.) Additionally, one or more nozzles may be placed in conjunction with the fiber optic just above the target surface being scanned. The one or more nozzles may be scanned, themselves, as illustrated, for example, in Figures 9, 10, 18 and 19, or the nozzles may be fixed to the handpiece, as illustrated, for example, in Figures 20-26.

In Figures 14a and 14b, two nozzles 163 for outputting atomized fluid particles are placed within the disk 160 at one hundred eighty degrees from each other. The two nozzles 163 are supplied with air and/or water to generate a thin layer of atomized fluid particles. The thin layer of atomized fluid particles is preferably consistent over the scanning pattern or fixed location (e.g., Figure 25 embodiment) of the electromagnetic energy impinging on the target surface. In addition to two nozzles, a greater number of nozzles 163 may be implemented, as

shown in phantom in Figure 14b. The number of atomization nozzles may be adjusted according to design parameters. Figures 15a and 15b illustrate an embodiment where several fine nozzle outputs 165 are placed along the height of the mist disk 167. In Figure 15b, a relatively large number of output nozzles 165 are also distributed along an inner circumference of the mist disk 167. The number of nozzles 165 along the height and along the circumference of the mist disk 167 can be adjusted in accordance with design parameters. The double-ended arrows shown in Figures 14a and 15a show that, in alternative embodiments, the nozzles within the disks may be moved along the axes of the arrows. In the presently preferred embodiment, the mist disks are removable from the scanning housing, and are all interchangeable, to thereby accommodate a large variety of different atomized distribution patterns which can be placed above the target surface. Figures 16a and 16b illustrate another embodiment where a misting substance 170 , such as a fabric or a very thin screen, or other substance, is placed between the radially outwardly located air and/or water supply lines/sources 173 and the scanning area of the electromagnetic energy. Figures 16a and 16b illustrate a plurality of output nozzles being positioned radially outwardly of the material, but in alternative embodiments only a single output nozzle may be supplied along the height in the mist disk.

Figure 17 illustrates a scanning housing where a motor 135 scans a fiber optic 137, and where a single air supply 175 is directed in a direction above the target surface basically parallel to the surface being scanned by the fiber optic 137. A fluid supply 177 is positioned between the scanned fiber optic 137 and the pressurized air supply 175, for directing fluid, such as water, into a pressurized exit path of the air supply 175. With a proper construction of the exit of the fluid line 177, the resulting combination of the pressurized air line 175 and fluid line 177 is to create a distribution of fluid particles between the scanned fiber tip 145 and the target surface.

The air and water lines may be placed closer to the fiber optic in alternative embodiments and may be configured in various orientations relative to one another,

so long as fluid particles are generated in a distribution comprising a thinlayer above the target surface. An additional air and water supply line is illustrated in phantom in Figure 17, and additional air and water lines may be added in accordance with design parameters.

Figure 18 illustrates an embodiment where a motor 135a scans a fiber optic 137 and where, additionally, a motor 135b scans an air and/or water line 180. The two motors are preferably designed to work together to optimize a placement of atomized fluid particles at the output of the scanned fiber optic 137, to thereby achieve consistent results on the target surface. Figure 19 illustrates an additional embodiment where a second motor 135b is used to scan an air and/or water supply 180 to dynamically place a consistent layer of atomized fluid particles in front of the output end of the movable fiber optic 137. The two motors may work together, based upon information obtained by a surface model of the target being scanned, for example, the surface model being predetermined or computer generated in accordance with known technology, such as disclosed in U.S. Patent Number 5,588,428.

Delivery systems comprising hand-held pieces with few or no moving parts are disclosed in Figures 20-26. In the embodiments of Figures 20-26 the handpieces themselves are moved to advance the electromagnetic energy over the target surface, as distinguished from the electromagnetic energy being scanned within the housings. It was mentioned above that in other embodiments similar technology may be incorporated into hand-held pieces wherein few or substantially all of the parts therein are fixed and do not move, and wherein the hand-held pieces are moved instead. It was also mentioned, in connection with the mist disks of Figures 14-16, that any assembly for providing a thin layer of atomized fluid particles just above the target surface may be implemented such as, for example, a single nozzle (without a mist disk) placed just adjacent to a fiber optic for providing an atomized distribution of fluid particles to the fiber optic or other means of introducing electromagnetic radiation, and the electromagnetic radiation

may or may not be scanned. The above disclosure is thus intended to apply to the embodiments of Figures 20-26, as well.

In Figure 20, a handpiece 180 comprises a trunk fiber optic 183 coupled to a ferrule 184 for outputting electromagnetic radiation onto a reflector 188, which preferably comprises a mirror, parabolic mirror or prism. The handpiece 180 comprises a first tissue contacting arm181 and a second tissue contacting arm 182. The two tissue contacting arms 181, 182 are preferably disposed opposite to one another. In accordance with a modified embodiment, one or more contacting arms (as distinguished from two tissue contacting arms) may be used, taking on basically any form so long as the one or more contacting arms provide a function of spacing the source of electromagnetic energy from the target surface. For example, in one modified embodiment, the one or more contacting arms may comprise a mist disk. In another modified embodiment, the one or more contacting arms may be constructed to contact another surface, such as another part of the patient, the patient's chair, or the floor, while still providing the function of spacing the source of electromagnetic energy from the target surface. In other modified embodiments, three or more tissue contacting arms may be disposed at, for example, about 120 degrees, 240 degrees and 360 degrees. In another embodiment, the tissue contacting arm or arms are part of and form at least a partial enclosure, such as a hemispherical enclosure. In yet another embodiment, the tissue contacting arms form at least a partial cylindrical, rectangular or other enclosure. The contacting surface of the enclosure (i.e., the surface that contacts the target surface) may thus comprise one or more points for actually touching the target surface (corresponding to one or more contacting legs), or may comprise a circular, oval, rectangular or other continuous or non-continuous perimeter for actually touching the target surface. For example, the contacting arms may form an oval, hemispherical enclosure, such as that of an upside down spoon, wherein the contacting surface of the oval, hemispherical enclosure forms an oval shape or edge for touching the target surface. Thus, in use, an oval shape on the target surface would be enclosed by the oval, hemispherical configuration. As used herein, the term "hemispherical"

is not intended to define half of a sphere but, rather, to define any closed surface with an opening for contacting the target surface. Thus, in an embodiment wherein the hemispherical configuration forms a rectangular edge for contacting the target surface, the enclosure may have any of a variety of shapes such as for example half or a sphere that transitions into the rectangular edge, or an open ended cubical enclosure with the rectangular edge. The general shapes constructions of the one or more contacting arms, as set forth in this paragraph, also apply to the embodiments described below with reference to Figures 21-26. The distal ends of the tissue contacting arms are preferably rounded or smooth-surfaced to allow the tissue contacting arms to glide over the target surface, such as a patient's skin, tissue, crystal or glass. In one modified embodiment, at least one of the distal ends comprises a ball roller.

A moisture output 190 directs moist air and/or water or an atomized air/water spray into the path of the electromagnetic energy from the parabolic mirror or prism 188. Water from the moisture output 190 can help to allow the tissue contacting arms to slide over the target surface. In one embodiment, water or another fluid, or an additive to water, having lubricating properties, may be emitted from the moisture output 190. For example, soft water may be emitted from the moisture output 190. As presently preferred, the moisture output 190 comprises an atomizer for outputting atomized fluid particles into the path of the electromagnetic energy above or on the target surface 192, and the parabolic mirror or prism 188 focuses the electromagnetic energy into an interaction zone above, on or within (interstitially) the target surface 192. A suction 194 removes excess moist air and/or atomized fluid particles. The suction 194 is preferably disposed opposite to the moisture output 190 to facilitate a fluid flow path from the moisture output 190, through the interaction zone, and out through the suction 194.

Figure 21 illustrates a similar configuration, with a fiber optic tip 196 carrying the electromagnetic energy to the interaction zone. As presently embodied, the fiber optic tip 196 terminates adjacent to the interaction zone, but other configurations are also possible. Figures 22 and 23 correspond to the

embodiments of Figures 20 and 21, respectively, with each of Figures 22 and 23 comprising an additional moisture output 190.

Figure 24 illustrates a hand-held piece with a fiber optic 200 terminating within a ferrule 202. Electromagnetic energy from the fiber optic 200 impinges on a parabolic reflector or prism 204 and is then focused into the fiber tip 206. Air and water lines 208 direct air and water into a mixing chamber 210 for mixing and subsequent emission from the output 211 along the fiber tip 206 toward the target surface. As with the embodiment of Figure 20. the target surfaces of Figures 21-26 preferably comprise skin, but may alternatively comprise other materials such as crystal or glass. In accordance with a presently preferred embodiment, water particles from the mixing chamber 210 intersect the propagation path of electromagnetic energy from the fiber tip 206 within an interaction zone above the target surface. At least one tissue contacting arm 212 extends from the handpiece 198 for contacting the target surface. As with the embodiments of Figures 20-24, the tissue contacting arms and the structure of the hand-held piece 230 bridging the tissue contacting arms together, may be formed of stainless steel or a plastic, for example. Part or all of the tissue contacting arms and bridging structure may be formed of a transparent material, such as a transparent plastic.

At least one of the tissue contacting arms 212 comprises a proximal end 214, a distal end 216, and a suction passageway 218 extending therebetween. Each suction passageway 218 is preferably constructed to carry surplus fluids and debris from the target surface. In order to facilitate this end, one or more of the rounded surfaces (e.g., ball rollers) at the distal ends 216 may be configured to have a smaller or flatter profile to place the relative position(s) of the suction passageway 218 opening(s) closer to the target surface. In one embodiment, the opening or openings of the suction passageway(s) 218 may be placed within the rounded surface(s) or ball roller(s) at the distal end(s) 216. Each suction passageway 218 removes water particles that have been emitted from the mixing chamber 210 and carries them proximally through the suction passageway 218 and out of the handpiece 198. Another suction passageway may be disposed in a second tissue

Cont'd

contacting arm 220. Additional tissue contacting arms may be implemented, such as a third tissue contacting arm, with or without additional suction passageways. In another embodiment, the tissue contacting arms are part of and form an enclosure, such as a hemispherical enclosure. The distal ends of the tissue contacting arms are preferably rounded or smooth-surfaced to allow the tissue contacting arms to slide over the target surface, such as a patient's skin. In a modified embodiment, one or more of the distal ends may comprise a ball roller. Regardless of the shape of the distal end of the tissue contacting arm, water from the moisture output 210 (or, for example, the moisture output 190 of Figures 20-23) or can help the tissue contacting arm or arms glide over the target surface. The air and water lines 208 may be configured to output, soft water or another fluid, or an additive to water, having lubricating properties. As with the embodiments of Figures 20-24, the tissue contacting arms and the structure of the hand-held piece 230 bridging the tissue contacting arms together, may be formed of stainless steel or a plastic, for example. Part or all of the contacting arms 240 and the bridging structure may be formed of a transparent material, such as a transparent plastic.

As an alternative to the mixing chamber 210 of Figure 24, one or more atomizers, mist generators, mist disks, or moist air outputs may be used instead and/or disposed in or connected to one or more of the tissue contacting arms 212. The atomizers, mist generators, mist disks, or moist air outputs are preferably constructed to place atomized fluid particles or moist air into an interaction zone within the path of the electromagnetic energy from the fiber tip 206 above the target surface. In a modified embodiment, the fiber tip 206 is omitted and the parabolic mirror or prism 204 or another suitable light bender, is used to focus or direct electromagnetic energy directly into an interaction zone or onto the target surface. In one embodiment, the electromagnetic energy is focused into an interaction zone above the target surface. In other embodiments in connection with Figures 20-26, with or without a fiber tip 206, and with a mixing chamber or alternatively with an atomizer, mist generator, mist disk, or moist air output, the electromagnetic energy can be directed onto the target surface with one or more

collimating, focusing, or diverging optics or reflectors. For example, with reference to Figure 25, a hand-held piece 230 comprises a mirror, parabolic mirror or prism 232 (shown in phantom) and an output optic 234 (shown in phantom) which comprises a collimating, focusing, or diverging lens. A trunk fiber optic (not shown) directs electromagnetic radiation onto the parabolic mirror or prism 232, and the parabolic mirror or prism 232 bends the electromagnetic radiation into the output optic 234 for subsequent output of the electromagnetic radiation through the output lens 235. As presently embodied, the mirror 232 and output optic 234 are disposed and protected within the hand-held piece 230, and the output lens 235 is exposed for cleaning. In a modified embodiment, the output optic 234 and the output lens 235 may comprise an integral unit

In Figure 25 a shaft portion 236 of the hand-held piece 238 is preferably constructed to rotatably connect to a source fiber via a standard RHP or SMA type coupling 236. Thus, as presently embodied, the hand-held piece 230 can be rotated about a longitudinal axis of the shaft portion. An angle A1 between the longitudinal axis of the shaft portion 236 and a line normal to the target surface is preferably set at one of 0,15. 30, 45, 60, 75, and 90 degrees. In a modified embodiment. the hand-held piece 230 may be adjustable between some or all of these angles. The line normal to the target surface, in accordance with one preferred embodiment, is defined to be parallel to a longitudinal axis of one of the tissue contacting arms 240. In an embodiment wherein two tissue contacting arms 240 are used, the "line normal to the target surface" can be defined as a line parallel to a plane containing both of the tissue contacting arms. Another way of defining A1 is the angle, measured from the longitudinal axis of the shaft portion 236, to which the parabolic mirror or prism 232 bends the electromagnetic radiation. In an embodiment wherein the angle A1 is zero, the parabolic mirror or prism 232 may be omitted altogether. The rotatable shaft portion and angle A1 constructions may similarly be incorporated into the constructions of Figures 20-24.

The hand-held piece 230 preferably comprises an air line 242 and a water line 244 both of which feed into a mixing chamber 246 for mixing thereof, and for

the subsequent emission of water particles from the moisture output 248, preferably into an interaction zone within the path of electromagnetic radiation from the lens 234. A vacuum source 250 is preferably disposed in at least one of the tissue contacting arms 240. The vacuum source 250 is preferably constructed, and disposed at a height, sufficient to remove excess water and not to interfere with the target surface. As with the embodiments of Figures 20-24, the tissue contacting arms may be part of and form an enclosure, such as a hemispherical enclosure, to enhance the efficacy of the vacuum source 250.

As an alternative to the mixing chambers 246, mist disks, such as illustrated in Figures 14-16, may be fitted between the tissue contacting arms 240 for providing, among other things, a spacing between the hand-held pieces and the target surface. As another alternative to the mixing chambers 246, one or more atomizers, mist generators, or moist air outputs (fluid outputs) may be disposed in, connected to or fitted between the tissue contacting arms 212. These mist disks may also provide the suction means, or the suction means may be provided above or below the mist disks or fluid outputs, such as at or near the ports 250 or 260. In one embodiment these spacing means can be about 3 millimeters in height or may be constructed to provide bounded layers of atomized fluid particles, for example, of about 3 millimeters in height. Other substantially different sizes for different heights may be used in other embodiments and in accordance with design parameters. When a substantially non-thermal cutting effect is desired in accordance with one aspect of the present invention, for example, the height of the spacing means can be varied so long as the resulting electromagnetically-induced disruptive forces are imparted onto the target surface, preferably without charring. The size and height of the spacing means can range, for example, in accordance with the target, laser, and type and distribution of air and/or fluid particles selected. A collimated beam, for example, may facilitate greater dimensions in the spacing means.

The mist disks for use with the hand-held piece 230 may comprise feet 262, as shown in Figure 26. In Figure 26 the tissue contacting arms 240 are modified, in

accordance with one aspect of the present invention, to accommodate mist disks or mist apparatus 263 with feet 262. The mist apparatus 263 are preferably fed by air and/or water lines (not shown), which empty into mixing chambers 265 formed by the mist apparatus 263. The mixing chambers 265 form moisture outputs for outputting fluid particles into, for example, the path of the electromagnetic radiation.

As with the embodiments of Figures 20-25, the mixing chambers 265 and moisture outputs may comprise nozzles, which may be either permanently installed or interchangeable. Different nozzles may be configured to generate different angles of output and/or different fluid flow characteristics, such as different densities and distributions of atomized fluid particles. The above discussions of engineered combinations of atomized fluid particles is incorporated herein by reference. Light or heavy densities of atomized fluid particles, and particles of different sizes, may be engineered, for example. Wide angle insertable nozzles, for example, may generate relatively wide cone angles of atomized fluid particles (e.g., cones spanning plus or minus 45 degrees from a line parallel to the target surface), and narrow angle insertable nozzles may generate relatively narrow cone angles of atomized fluid particles (e.g., cones spanning plus or minus 15 degrees from a line spanning from the atomizer to the point of contact of the electromagnetic energy and the target surface).

The illustrated embodiment of Figure 26 shows the modified tissue contacting arms 240 extending in a substantially parallel fashion for accommodating the removable mist apparatus 263. The mist apparatus 263, may be formed of stainless steel, for example, or of a disposable material, such as plastic, in accordance with one embodiment of the present invention. Part or all of the plastic may be transparent in accordance with another aspect of the present invention. The fluid particle generating apparatus 263 may comprise one post 264 for each modified tissue contacting arm 240. The posts may be connected or separate, or may comprise a cylinder or semi-cylinder. Moreover, each of the posts 264 of the fluid particle generating apparatus 263 may comprise one or more

vacuum sources. The distal ends of the feet 262 are preferably rounded or smooth-surfaced to allow the feet 262 to glide over the target surface, such as a patient's skin. In modified embodiments, the feet 262 may comprise ball rollers. As with the embodiments of Figures 20-25, water from the moisture output can help to allow the tissue contacting arms to slide over the target surface. In one embodiment, soft water or another fluid, or an additive to water, having lubricating properties, may be emitted from the moisture output.

In other modified embodiments, single-nozzle moisture outputs oriented to output distributions of fluid particles preferably in directions substantially perpendicular to directions of incidence of the electromagnetic radiation, such as shown in Figure 24, can be implemented. In addition, a piezoelectric atomizer for generating a fine spray may be used. Moreover, various configurations implementing fluid injectors, having structures similar to fuel injectors of internal combustion engines, for example, may be used to generate atomized distributions of fluid particles.

In other modified embodiments, only a single line, as distinguished from separate water and separate air lines, is used to deliver moist air. The moist air may comprise a colloidal suspension of water droplets, very humid air (about 100% humid), cool or cold steam as from a cold humidifier, or water vapor from dry ice. A pulsing valve may be incorporated to control the delivery of fluid. In another embodiment, a mono-water droplet dispersor may be used to supply single droplets, or droplets of relatively small numbers, to the interaction zone. Sprays can be used which are fed only by water without any assistance by an air line. A nebulizer, which uses air pressure and water to output atomized fluid particles through a small orifice, can be implemented. The nebulizer may comprise an ultrasonic or sonic device, and the atomized fluid particles may comprises water droplets having diameters ranging from about 5 to about 20 microns, or larger.

In accordance with the present invention, the fluid particles placed above the target surface may comprise materials other than, or in addition to, water. The fluid may comprise, for example, a medicated substance, a sterilized substance, or

an anesthetic. U.S. Patent No. 5,785,521 is expressly incorporated herein by reference to disclose, for example, various means and types of conditioned fluids which may be used in conjunction with a source of electromagnetic energy.

The present invention, which implements electromagnetically induced cutting to cut, remove, or otherwise impart disruptive forces onto relatively large surface areas of an epidermis, can be implemented on other target surfaces as well. The present invention is not intended to be limited to operating on skin, or even tissue. One preferred application, however, involves removing tissue from relatively large surface areas of the epidermis for cosmetic purposes. For example, cosmetic surgery may be implemented using the present device on the face of a patient. Other conventional means for scanning a collimated or non-collimated beam, which are not disclosed above, may be implemented for achieving this purpose. The apparatus of the present invention, however, differs from the prior art in implementing the distributions of fluid particles or moist air between or within the impinging electromagnetic energy and the target surface. A particular laser source, as disclosed in U.S. Application Serial Number 08/903,187 is preferred, the contents of which are expressly incorporated herein by reference.

In a presently preferred embodiment of cosmetic surgery on the epidermis of a patient. the fluid particles or moist air may comprise at least one anesthesia and/or medication. Medications can include drugs for relieving pain (analgesics), such as Acetaminophen; drugs for causing a loss of general sensation (anesthetics) and vasal constrictors, such as lidocaine, epinephrine, or a combination of lidocaine and epinephrine; and substances able to kill or inhibit growth of certain microorganisms (antibiotics), such as penicillin or tetracycline. In the category of anesthetics. one composition would comprise lidocaine + diethyl-amimacet-2,6-xylidins. Epinephrine can be added to this composition. and the resulting product may provide an anesthetic affect for a period from about 45 minutes to 3 hours. Amino esters may also be used as anesthetics in other embodiments, wherein such amino esters may comprise, for example, procaine, 2-chloroprocaine and/or tetracine. In other embodiments, lidocaine can be combined with one or more of

prilocaine, etidocaine, mepiracaine and bupivacaine. The medications can be emitted from a separate channel and/or orifice, or can be emitted from the moisture outputs.

In one embodiment of the present invention, botulinum toxin can be emitted from the moisture outputs, preferably on a final pass, for preventing wrinkling of the skin during healing. Botulinum toxin is a generic term embracing the family of toxins produced by the anaerobic bacterium Clostridium botulinum and, to date, seven immunologically distinct neurotoxins serotype have been identified. These have been given the designations A, B, C, D, E, F and G. For further information concerning the properties of the various botulinum toxins, reference is made to the article by Jankovic and Brin, The New England Journal of Medicine, Vol. 324, No. 17, 1990. pp. 1186-1194, and to the review by Charles L. Hatheway in Chapter 1 of the book entitled Botulinum Neurotoxin and Tetanus Toxin, L. L. Simpson, Ed., published by Academic Press Inc. of San Diego, Calif., 1989, the disclosures in which are incorporated herein by reference. Botulinum toxin is obtained commercially by establishing and growing cultures of C. botulinum in a fermenter and then harvesting and purifying the fermented mixture in accordance with known techniques. Botulinum toxin type A, the toxin type generally utilized in treating neuromuscular conditions, is currently available commercially from several sources: for example, from Porton Products Ltd. UK, under the trade name "DYSPORT," and from Allergan, Inc., Irvine, Calif., under the trade name BOTOX.RTM. Botulinum Toxin Type A purified complex. In other embodiments, any of the serotypes B through G of Botulinum neurotoxin may be used, as well. The medications can be emitted from a separate channel and/or orifice, or can be emitted from the moisture outputs.

When multiple passes of the electromagnetically induced cutter are conducted over the surface being ablated, the medication and/or anesthesia within the atomized fluid particles is continuously delivered onto the tissue, to thereby hydrate, relax, medicate, and/or otherwise treat or medicate the tissue. In alternative embodiments, the mist is applied only on the second and subsequent

passes over the surface. The mist may be applied at selected times during a single pass, and/or may be applied during selected passes of the laser over the surface. Similarly, the type of conditioning of the fluid may be selectively applied.

According to one aspect of the present invention, materials can be removed in one embodiment from a target surface by cutting forces different from conventional thermal cutting forces. In another embodiment, the apparatus of the present invention can be used to impart thermal energy onto the tissue subsequent to the substantially non-thermal cutting or ablating, for inducing deep cutting and coagulation, for example. For example, a first scan can induce non-thermal or reduced thermal cutting, and a subsequent scan can be used to apply thermal energy to the surface for inducing coagulation. In yet another embodiment, a reduced amount of atomized fluid particles (or moisture) may be used to simultaneously impart a combination of at least partially mechanical cutting (from expanding moisture) and thermal cutting (from the laser to impart coagulation, for example).

In one particular embodiment, a first pass over the surface of primarily non-thermal cutting is implemented with the fluid from the moisture output preferably comprising an anesthetic and a vasal constrictor (e.g., epinephrin). In this first pass, portions of the epidermis are preferably removed. A second pass is then performed, preferably with a lesser amount of fluid from the moisture output. The fluid is slightly or moderately reduced, or even eliminated, for greater cutting of the dermal layer of the skin and coagulation of vessels. For deeper wrinkles, additional passes similar to the second pass can be performed. Any of the above mentioned forms of Botulinum neurotoxin may be used an any point in time, such as, for example, as an after or in-between-laser treatment, to maintain skin smoothness. Prior art lasers typically do not apply any medication medium during the passing of laser over the skin, thereby causing the skin to become irritated and red. In contrast to prior art lasers which typically impart thermal cutting forces onto the skin, the electromagnetically induced cutter of the present invention, when operated in a non-thermal or reduced-thermal cutting mode in accordance with one aspect of the present invention, preferably does not deliver any substantial amount of heat to the

tissue. As mentioned above, in this cutting mode the exploded atomized fluid particles are cooled by exothermic reactions before they contact the target surface. Thus, in accordance with one aspect of the present invention, atomized fluid particles of the present invention are heated, expanded, and cooled before contacting the target surface. Prior-art devices, which thermally operate on the skin, may have negative side effects associated therewith in connection with the medical procedure and the subsequent healing of the tissue. The present invention may, additionally, be able to ablate extremely thin layers of tissue, relative to existing laser skin surgery devices. Moreover, the non-thermal or reduced-thermal cutting mode, as a result of the mechanical cutting mechanism achieved from the expanding fluid particles, may be configured to cut at a particular depth of skin, so that only the crests of wrinkles are removed and part or all of the valleys are left in tact. The mechanical cutting nature of the non-thermal or reduced-thermal cutting mode may also be able to more evenly cut through hair and hair follicles, to thereby more evenly ablate the skin surface.

In accordance with one aspect of the present invention, substantially non-thermal cutting or reduced-thermal cutting alone, or in combination with the medicated atomized fluid particles, can serve to reduce erythema (skin redness) and reduce edema (swelling). Moreover, the present invention in accordance with one embodiment can serve to reduce unwanted thermal damage to adjacent tissue. For example, direct and/or adjacent melanocytes may not be substantially thermally affected with the present invention, thus attenuating hypo or hyper pigmentation effects, which can occur with prior-art chemical peel, derma-abrasion (use of wire brush), and thermal-cutting laser procedures. The present invention further can serve to reduce post and intra-operative pain and discomfort. For example, burning sensations and effects experienced by the patient can be attenuated.

Relatively small surface areas, or small thicknesses, of the skin may be treated in low wattage modes. Additionally, a relatively small amount of fluid may be used. Alternatively, the electromagnetic energy may be applied in a defocused mode, for a net decrease in energy density on the target surface.

The above-mentioned delivery of the atomized fluid particles, which may comprise medication and/or anesthesia, onto the skin during or close in time with the cutting or ablating operation serves to hydrate, relax. medicate, and/or otherwise treat or medicate the tissue. The atomized fluid particles may be delivered into the interaction zone contemporaneously with each pulse of electromagnetic radiation or, alternatively, may be continuously delivered into the interaction zone.

Although the hydration of the soft tissue is a benefit in accordance with one aspect of the present invention, too much water can interfere with the optimal execution of the medical procedure. A percentage of the atomized fluid particles not within the path of the electromagnetic radiation will accumulate on the surface of the target surface. Suction from the vacuum sources can be used to remove excess or unwanted liquid from the target surface or adjacent areas. Cut tissue can be carried by the excess water and removed by the suction. In one embodiment, the target surface can be oriented so that gravity will drain off unwanted liquid. The suction is preferably additionally, or alternatively, used to remove airborne atomized fluid particles that are not in the interaction zone. One or more suction channels may be placed in a mist disk, as mentioned above. for removing unwanted, airborne atomized fluid particles not within the path of the electromagnetic energy. The suction channels may be placed between moisture output channels at the same height, or at different heights in which case the suction channels may also be placed directly above or below the moisture outputs channels. Utilization of the above-mentioned moist air, alone or in combination with atomized fluid particles, may help to attenuate an amount of excess fluid accumulating on the target surface.

Although an exemplary embodiment of the invention has been shown and described, many changes, modifications and substitutions may be made by one having ordinary skill in the art without necessarily departing from the spirit and scope of this invention.